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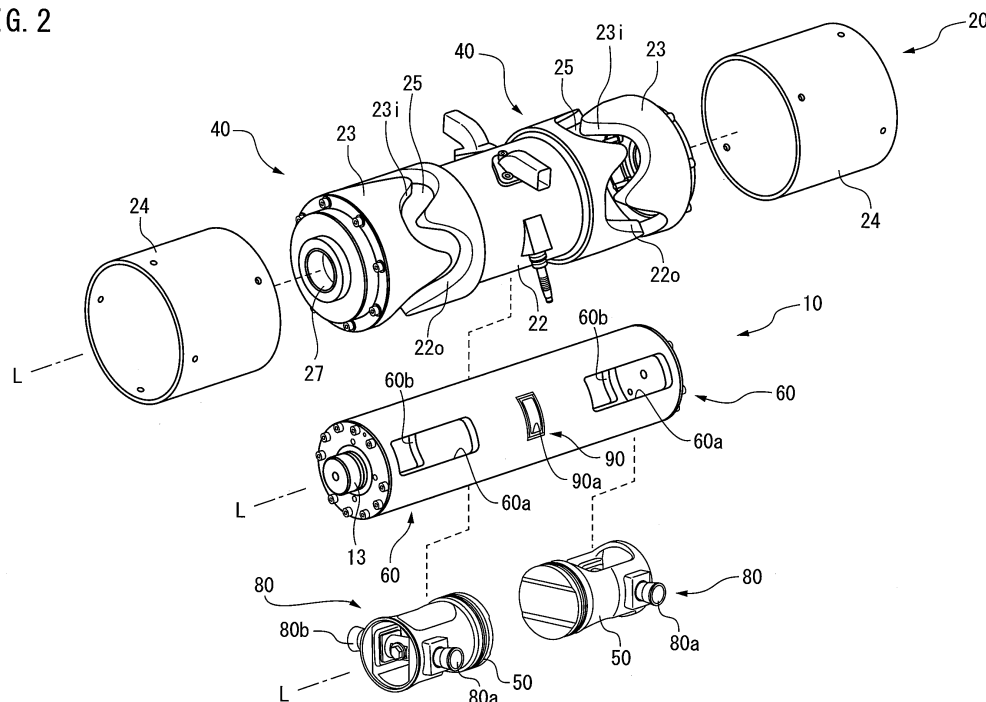
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(54) **INTERNAL COMBUSTION ENGINE**

(57) An internal combustion engine 1 is provided with a cylinder 10 able to rotate about a rotational axis L, a combustion chamber defined in the cylinder, and drive parts 40. The drive parts are provided with pistons 50 housed in the cylinder able to slide in the rotational axis direction and defining a combustion chamber, slots 60 formed in the circumferential surface of the cylinder, cams 70 stationarily set around the slots, and followers 80 extending from the pistons through the slots to the cams. The slots are configured to limit relative movement

of the followers together with the pistons with respect to the cylinder in a circumferential direction of the rotational axis, while allowing relative movement of the followers together with the pistons with respect to the cylinder in a direction of the rotational axis. Combustion performed in the combustion chamber moves the pistons together with the followers along profiles of the cams to thereby rotate the cylinder about the rotational axis, and the rotation of the cylinder is taken out as engine output.

FIG. 2



Description

FIELD

[0001] The present disclosure relates to an internal combustion engine.

BACKGROUND

[0002] An internal combustion engine is known in the art, which converts reciprocating motion of a piston to rotary motion by a crank mechanism and outputs the same (for example, see PTL 1). In such an internal combustion engine, it is also known that making a stroke length larger than a cylinder bore diameter will reduce a fuel consumption rate.

[CITATION LIST]

[PATENT LITERATURE]

[0003] [PTL 1] Japanese Unexamined Patent Publication No. 2017-207053

SUMMARY

[TECHNICAL PROBLEM]

[0004] However, for example, making the stroke length larger than the cylinder bore diameter will enlarge a crank radius, which enlarges dimensions of the internal combustion engine. Therefore, so long as using a crank mechanism, there are limits to how much more compact an internal combustion engine can be made.

[SOLUTION TO PROBLEM]

[0005] According to the present disclosure, there is provided an internal combustion engine, comprising: a cylinder able to rotate about a rotational axis; a combustion chamber defined in the cylinder; and a drive part, the drive part comprising: the drive parts comprised of a piston housed in the cylinder to be able to slide in a direction of the rotational axis and defining the combustion chamber; a slot formed in a circumferential surface of the cylinder at an opposite side to the combustion chamber relative to the piston; a cam stationarily set around the slot, which cam has a profile oscillating in a direction of the rotational axis while being annular in a circumferential direction of the rotational axis; and a follower extending from the piston through the slot to the cam, and configured to move together with the piston along profile of the cam, wherein the slot is configured to limit relative movement of the follower together with the piston with respect to the cylinder in a circumferential direction of the rotational axis, while allowing relative movement of the follower together with the piston with respect to the cylinder in a direction of the rotational axis, wherein combustion

performed in the combustion chamber moves the piston together with the follower along profile of the cam to thereby rotate the cylinder about the rotational axis, and wherein the rotation of the cylinder is taken out as engine output.

[ADVANTAGEOUS EFFECTS OF INVENTION]

[0006] An internal combustion engine can be made more compact.

BRIEF DESCRIPTION OF DRAWINGS

[0007]

FIG. 1 is a schematic overall perspective view of an internal combustion engine of the embodiment according to the present disclosure.

FIG. 2 is a schematic disassembled view of an internal combustion engine of the embodiment according to the present disclosure.

FIG. 3 is a schematic cross-sectional view along a rotational axis of an internal combustion engine of the embodiment according to the present disclosure.

FIG. 4 is a schematic partial cross-sectional view along a rotational axis of an internal combustion engine of the embodiment according to the present disclosure.

FIG. 5 is a schematic cross-sectional view along a symmetry plane of an internal combustion engine of the embodiment according to the present disclosure.

FIG. 6 is a schematic perspective view of a piston of the embodiment according to the present disclosure.

FIG. 7 is a schematic enlarged view of a cam and follower of the embodiment according to the present disclosure.

FIG. 8 is a graph showing a behavior of a piston of the embodiment according to the present disclosure.

FIGS. 9(A) to 9(C) are schematic views of an internal combustion engine of the embodiment according to the present disclosure in an intake stroke, wherein FIG. 9(A) is a cross-sectional view showing a positional relationship between communication holes and an intake hole etc., FIG. 9(B) is a side view showing a positional relationship between cams and followers, and FIG. 9(C) is a side view showing a positional relationship between slots and followers.

FIGS. 10(A) to 10(C) are schematic views of an internal combustion engine of the embodiment according to the present disclosure in a compression stroke, wherein FIG. 10(A) is a cross-sectional view showing a positional relationship between communication holes and an intake hole etc., FIG. 10(B) is a side view showing a positional relationship between cams and followers, and FIG. 10(C) is a side view showing a positional relationship between slots and followers.

FIGS. 11(A) to 11(C) are schematic views of an in-

ternal combustion engine of the embodiment according to the present disclosure when a rotational angle of a cylinder is in an ignition angle range, wherein FIG. 11(A) is a cross-sectional view showing a positional relationship between communication holes and an intake hole etc., FIG. 11(B) is a side view showing a positional relationship between cams and followers, and FIG. 11(C) is a side view showing a positional relationship between slots and followers. FIG. 12 is a schematic view of an internal combustion engine of the embodiment according to the present disclosure when a rotational angle of a cylinder is in an ignition angle range and a side view showing a positional relationship between notches of a piston, communication holes, and a spark plug.

FIGS. 13(A) to 13(C) are schematic views of an internal combustion engine of the embodiment according to the present disclosure in an expansion stroke, wherein FIG. 13(A) is a cross-sectional view showing a positional relationship between communication holes and an intake hole etc., FIG. 13(B) is a side view showing a positional relationship between cams and followers, and FIG. 13(C) is a side view showing a positional relationship between slots and followers.

FIGS. 14(A) to 14(C) are schematic views of an internal combustion engine of the embodiment according to the present disclosure in an exhaust stroke, wherein FIG. 14(A) is a cross-sectional view showing a positional relationship between communication holes and an intake hole etc., FIG. 14(B) is a side view showing a positional relationship between cams and followers, and FIG. 14(C) is a side view showing a positional relationship between slots and followers.

FIG. 15 is a schematic view showing an internal combustion engine of the embodiment according to the present disclosure in an expansion stroke.

FIG. 16 is a schematic view showing an internal combustion engine of the embodiment according to the present disclosure in a compression stroke and exhaust stroke.

FIG. 17 is a schematic view showing an internal combustion engine of the embodiment according to the present disclosure in an intake stroke.

FIG. 18 is a schematic cross-sectional view along a rotational axis of an internal combustion engine of another embodiment according to the present disclosure.

FIGS. 19(A) and 19(B) are schematic views showing another embodiment of a follower, wherein FIG. 19(A) is a partial cross-sectional view along a rotational axis and FIG. 19(B) is a cross-sectional view along a line B-B shown in FIG. 19(A).

FIGS. 20(A) and 20(B) are schematic views showing another embodiment of a cam and follower, wherein FIG. 20(A) is a partial cross-sectional view along a rotational axis and FIG. 20(B) is a cross-sectional

view along a line BB-BB shown in FIG. 20(A).

DESCRIPTION OF EMBODIMENTS

[0008] FIG. 1 to FIG. 7 show an internal combustion engine 1 of the embodiment according to the present disclosure. This internal combustion engine 1 overall has a cylindrical shape or columnar shape having a longitudinal center axis (for example, see FIGS. 1, 3, and 4). This longitudinal center axis matches with a rotational axis L which will be explained later. Further, the internal combustion engine 1 of the embodiment according to the present disclosure is formed substantially symmetrically with respect to a symmetry plane P vertical to the rotational axis L (for example, see FIGS. 3 and 4).

[0009] The internal combustion engine 1 of the embodiment according to the present disclosure is a four-stroke engine. In another embodiment according to the present disclosure (not shown), the internal combustion engine 1 is a two-stroke engine. On the other hand, in the internal combustion engine 1 of the embodiment according to the present disclosure, spark ignition combustion is performed. In an internal combustion engine of another embodiment according to the present disclosure (not shown), compression ignition combustion, or premixed compression ignition combustion (HCCI (homogeneous charge compression ignition) combustion or PCCI (premixed charge compression ignition) combustion) is performed. As fuel, a liquid fuel such as gasoline, diesel fuel, or alcohol, or a gaseous fuel such as liquefied petroleum gas (LPG), compressed natural gas (CNG), or hydrogen, is used.

[0010] The internal combustion engine 1 of the embodiment according to the present disclosure is provided with a single cylinder 10 able to rotate about the rotational axis L (for example, see FIGS. 2 to 4). The cylinder 10 overall has a hollow, cylindrical shape. Longitudinal center axes of an inner circumferential surface 11 having a cylindrical shape and an outer circumferential surface 12 having a cylindrical shape of the cylinder 10 respectively match the rotational axis L. In the embodiment according to the present disclosure, the cylinder 10 can rotate in an R direction (for example, see FIGS. 3 and 4).

[0011] The internal combustion engine 1 of the embodiment according to the present disclosure is further provided with an outer circumferential member 20 (for example, see FIGS. 2 to 4). This outer circumferential member 20 overall has a hollow, cylindrical shape. A longitudinal center axis of an inner circumferential surface 21 having a cylindrical shape of the outer circumferential member 20 matches with the rotational axis L. The above-mentioned cylinder 10 is housed in this outer circumferential member 20 to be able to rotate about the rotational axis L, therefore the outer circumferential member 20 is positioned around the cylinder 10. On the other hand, the outer circumferential member 20 of the embodiment according to the present disclosure is stationary set. That is, the outer circumferential member 20 is

set or mounted to be unable to rotate about the rotational axis L and to be unable to move in the rotational axis L direction.

[0012] The outer circumferential member 20 of the embodiment according to the present disclosure is comprised of a plurality of members. Specifically, the outer circumferential member 20 is provided with a center part 22, two end parts 23, 23, and two housings 24, 24 (for example, see FIGS. 2 to 4). The center part 22 has a hollow, cylindrical shape with open opposite ends in the rotational axis L direction, and is arranged on the symmetry plane P. The end parts 23, 23 respectively have hollow, cylindrical shapes with closed outside ends in the rotational axis L direction and open inside ends in the rotational axis L direction, and are arranged with spaces 25 from the center part 22 in the rotational axis L direction (for example, see FIGS. 2 and 4). The spaces 25 have annular shapes in the circumferential direction about the rotational axis L. The housings 24, 24 have hollow, cylindrical shapes with open opposite ends in the rotational axis L direction, and are fixed to the center part 22 and the corresponding end parts 23, 23 by for example bolts 26, 26 (for example, see FIGS. 3 and 4). As a result, the center part 22 and the end parts 23, 23 are connected to each other by the housings 24, 24 and the spaces 25, 25 are separated from the outside by the housings 24, 24. In this case, the inner circumferential surface 21 of the outer circumferential member 20 is comprised of an inner circumferential surface of the center part 22 and inner circumferential surfaces of the end parts 23, 23. In another embodiment (not shown), the outer circumferential member 20 is comprised of an integral member.

[0013] In the embodiment according to the present disclosure, the cylinder 10 is housed in the outer circumferential member 20 so that the outer circumferential surface 12 of the cylinder 10 slides with respect to the inner circumferential surface of the center part 22 (for example, see FIGS. 3 and 4). Further, projecting parts 13, 13, which are provided respectively at two ends in the rotational axis L direction of the cylinder 10, are held to be able to rotate about the rotational axis L, in corresponding through holes 27, 27, which are provided at two ends in the rotational axis L direction of the outer circumferential member 20 (for example, see FIG. 2 to 4). In this way, the cylinder 10 is held by the outer circumferential member 20 to be able to rotate about the rotational axis L. Note that, in the embodiment according to the present disclosure, the outer circumferential surface 12 of the cylinder 10 and the inner circumferential surfaces of the end parts 23, 23 are separated from each other. Further, in the embodiment according to the present disclosure, an output shaft (not shown) is connected to one projecting part 13.

[0014] The internal combustion engine 1 of the embodiment according to the present disclosure is further provided with a single combustion chamber 30 defined inside the cylinder 10 (for example, see FIGS. 3 and 4). This combustion chamber 30 is positioned on the sym-

metry plane P.

[0015] The internal combustion engine 1 of the embodiment according to the present disclosure is further provided with two drive parts 40, 40 arranged along the rotational axis L (for example, see FIGS. 1 to 4).

[0016] The drive parts 40, 40 of the embodiment according to the present disclosure are respectively provided with single pistons 50 (for example, see FIGS. 2 to 4). The pistons 50 are housed in the cylinder 10 to be able to slide in the rotational axis L direction. In this case, the piston 50 of one drive part 40 and the piston 50 of the other drive part 40 face each other inside the cylinder 10. The above-mentioned combustion chamber 30 is defined between these pistons 50, 50 in the cylinder 10. Note that, longitudinal center axes of the pistons 50 match the rotational axis L.

[0017] In the embodiment according to the present disclosure, recessed parts 52 are formed in top surfaces 51 of the pistons 50 (for example, see FIG. 6). The recessed parts 52 extend in diametrical directions of the pistons 50 and reach circumferential surfaces of the pistons 50. As a result, at the circumferential surfaces of the pistons 50 adjoining the top surfaces 51 of the pistons 50, two notches 52a, 52b are formed separated by 180 degrees in the circumferential direction about the rotational axis L. Further, in the embodiment according to the present disclosure, the recessed part 52 of one piston 50 and the recessed part 52 of the other piston 50 are aligned to each other in the circumferential direction about the rotational axis L. Therefore, the notches 52a, 52b of one piston 50 and the notches 52a, 52b of the other piston 50 are also aligned to each other in the circumferential direction about the rotational axis L.

[0018] Further, the drive parts 40, 40 of the embodiment according to the present disclosure are respectively further provided with pluralities of slots 60 which are formed in a circumferential surface of the cylinder 10 separated at equal intervals in the circumferential direction about the rotational axis L (for example, see FIGS. 2 to 4). In the embodiment according to the present disclosure, the slots 60 comprise two slots 60a, 60b separated from each other by 180 degrees in the circumferential direction about the rotational axis L. The slots 60a, 60b are respectively formed in the circumferential surface of the cylinder 10 at the opposite sides to the combustion chamber 30 relative to the pistons 50 (for example, see FIGS. 2 to 4). That is, the combustion chamber 30 is positioned at the inner side in the rotational axis L direction with respect to the pistons 50, while the slots 60a, 60b are positioned at the outer sides in the rotational axis L direction with respect to the pistons 50. Note that the slots 60a, 60b are aligned in the rotational axis L direction.

[0019] The slots 60a, 60b of the embodiment according to the present disclosure respectively have rectangular shapes elongated in the rotational axis L direction and are provided with two engaging surfaces 61u, 61d separated from each other in the circumferential direction about the rotational axis L and extending in the rotational

axis L direction (for example, see FIGS. 4 and 7). In this case, the engaging surfaces 61u are positioned at upstream sides in the rotational direction R about the rotational axis L while the engaging surfaces 61d are positioned at downstream sides.

[0020] The drive parts 40, 40 of the embodiment according to the present disclosure are respectively provided with single cams 70 (for example, see FIGS. 3 and 4). The cams 70 are stationarily set around the slots 60. Further, the cams 70 have profiles oscillating in the rotational axis L direction while being annular in the circumferential direction about the rotational axis L. Furthermore, in the embodiment according to the present disclosure, the profiles of the cams 70, 70 are respectively formed so that the pistons 50, 50 of the two drive parts 40, 40 are synchronized to each other.

[0021] In the embodiment according to the present disclosure, the cams 70 are comprised of groove cams. Specifically, the cams 70 are provided with outside end faces 22o of the center parts 22 in the rotational axis L direction, inside end faces 23i of the end parts 23 in the rotational axis L direction, and the spaces 25 of the outer circumferential members 20 defined by these end faces 22o, 23i (for example, see FIGS. 3, 4, and 7). These end faces 22o, 23i function as cam faces of the cams 70. In this case, the cams 70 may be held by the outer circumferential members 20. Further, the cam 70 of one drive part 40 and the cam 70 of the other drive part 40 may be held by the common outer circumferential member 20.

[0022] The drive parts 40, 40 of the embodiment according to the present disclosure are respectively provided with pluralities of followers 80 which are provided integrally with the pistons 50 and separated at equal intervals in the circumferential direction about the rotational axis L (for example, see FIGS. 2 to 4). In the followers 80 of the embodiment according to the present disclosure, the followers 80 comprise two followers 80a, 80b separated from each other by 180 degrees in the circumferential direction about the rotational axis L. Note that the followers 80a, 80b are aligned to each other in the rotational axis L direction. The followers 80a, 80b respectively extend from the pistons 50 through the slots 60a, 60b to the cams 70, and are configured to move along the profiles of the cams 70 (for example, see FIGS. 3 and 4).

[0023] Specifically, the followers 80a, 80b of the embodiment according to the present disclosure respectively are provided with sliders 81, arms 82, and rollers 83 (for example, see FIGS. 3, 4, and 6). The sliders 81 are fit into through holes 53 formed in circumferential walls of the pistons 50. Further, the sliders 81 have two engaging surfaces 81u, 81d extending in the rotational axis L direction. On the other hand, the arms 82 extend through the sliders 81 outward in a radial direction. In the embodiment according to the present disclosure, the arms 82 of the followers 80a and the arms 82 of the other followers 80b are integrally formed. At tips of the arms 82, rollers 83 are attached to be able to rotate about a

longitudinal center axis L1 of the arms 82. The followers 80a, 80b are fastened by fastening sleeves 84 to the pistons 50.

[0024] In an assembled state (for example, see FIGS. 3, 4, and 7), the rollers 83 engage with the cams 70. That is, circumferential surfaces of the rollers 83 abut against the cam faces 22o, 23i of the cams 70. As a result, the followers 80a, 80b can move together with the pistons 50 along the profiles of the cams 70.

[0025] Further, in an assembled state (for example, see FIGS. 3, 4, and 7), the sliders 81, 81 are housed in the slots 60a, 60b. As a result, the engaging surfaces 81u of the sliders 81 engage with the engaging surfaces 61u of the slots 60a, 60b and the engaging surfaces 81d of the sliders 81 engage with the engaging surfaces 61d of the slots 60a, 60b. For this reason, the sliders 81 are restricted from relative movement with respect to the cylinder 10 in the circumferential direction about the rotational axis L by the slots 60a, 60b. This means that rotation of the followers 80a, 80b about the rotational axis L causes rotation of the cylinder 10 together with the followers 80a, 80b about the rotational axis L, and that rotation of the cylinder 10 about the rotational axis L causes rotation of the followers 80a, 80b together with the cylinder 10 about the rotational axis L. On the other hand, the sliders 81 are allowed to move relative to the cylinder 10 in the rotational axis L direction. That is, the slots 60 of the embodiment according to the present disclosure are configured to restrict relative movement of the followers 80 together with the pistons 50 with respect to the cylinder 10 in the circumferential direction about the rotational axis L, while allowing relative movement of the followers 80 together with the pistons 50 with respect to the cylinder 10 in the rotational axis L direction.

[0026] The internal combustion engine 1 of the embodiment according to the present disclosure is further provided with a plurality of communication holes 90 formed in the circumferential surface of the cylinder 10 to be separated at equal intervals in the circumferential direction about the rotational axis L and to communicate with the combustion chamber 30. In the embodiment according to the present disclosure, the communication holes 90 comprise two communication holes 90a, 90b separated by 180 degrees in the circumferential direction about the rotational axis L (for example, see FIGS. 3 and 5). These communication holes 90a, 90b are aligned to each other in the rotational axis L direction, and are arranged on, for example, the symmetry plane P (for example, see FIGS. 3 and 4).

[0027] The internal combustion engine 1 of the embodiment according to the present disclosure is further provided with a single intake hole 90i formed at the center part 22 of the outer circumferential member 20 (for example, see FIG. 5). The intake hole 90i is aligned with the communication holes 90a, 90b in the rotational axis L direction. Further, the intake hole 90i in the embodiment according to the present disclosure is formed in the outer circumferential member 20 so that the intake hole 90i

communicates with the communication holes 90a, 90b when the rotational angle θ about the rotational axis L of the cylinder 10 is in a predetermined intake angle range IN. In the embodiment according to the present disclosure, as explained above, the outer circumferential surface 12 of the cylinder 10 slides against the inner circumferential surface 21 of the center part 22 of the outer circumferential member 20. For this reason, when the communication holes 90a, 90b face the inner circumferential surface 21 of the outer circumferential member 20, the communication holes 90a, 90b are closed by this inner circumferential surface 21, therefore the combustion chamber 30 is sealed. As opposed to this, when the cylinder 10 rotates about the rotational axis L to face the communication holes 90a, 90b with the intake hole 90i, the communication holes 90a, 90b communicate with the intake hole 90i, therefore the combustion chamber 30 communicates with the intake hole 90i through the communication holes 90a, 90b. An intake pipe 91i is connected with this intake hole 90i (for example, see FIGS. 1 and 5). For example, a fuel injector (not shown) for injecting fuel inside the intake pipe 91i, a throttle valve (not shown) for controlling the amount of intake flowing through the inside of the intake pipe 91i, etc. are arranged in the intake pipe 91i.

[0028] The internal combustion engine 1 of the embodiment according to the present disclosure is further provided with a single exhaust hole 90e formed at the center part 22 of the outer circumferential member 20 (for example, see FIG. 5). The exhaust hole 90e is aligned with the communication holes 90a, 90b in the rotational axis L direction, and therefore is also aligned with the intake hole 90i. Further, the exhaust hole 90e of the embodiment according to the present disclosure is formed or positioned in the outer circumferential member 20 so that the exhaust hole 90e communicates with the communication holes 90a, 90b when the rotational angle θ of the cylinder 10 is within a predetermined exhaust angle range EX. When the cylinder 10 rotates about the rotational axis L to face the communication holes 90a, 90b with the exhaust hole 90e, the communication holes 90a, 90b communicate with the exhaust hole 90e, and therefore the combustion chamber 30 communicates with the exhaust hole 90e through the communication holes 90a, 90b. An exhaust pipe 91e is connected with this exhaust hole 90e (for example, see FIGS. 1 and 5). For example, a catalyst for purifying exhaust gas (not shown), etc. are arranged in the exhaust pipe 91e.

[0029] The internal combustion engine 1 of the embodiment according to the present disclosure is further provided with a single spark plug housing hole 90s formed at the outer circumferential member 20 (for example, see FIG. 5). The spark plug housing hole 90s is aligned with the communication holes 90a, 90b in the rotational axis L direction, and therefore is also aligned with the intake hole 90i and exhaust hole 90e. A spark plug 91s is sealingly housed in spark plug housing hole 90s. The spark plug housing hole 90s of the embodiment according to

the present disclosure is formed or positioned in the outer circumferential member 20 so that the spark plug 91s faces the communication holes 90a, 90b when the rotational angle θ of the cylinder 10 is in a predetermined ignition angle range SP.

[0030] FIG. 8 shows behavior of the pistons 50 of the embodiment according to the present disclosure. In FIG. 8, the abscissa indicates the rotational angle θ of the cylinder 10 when referenced to a certain top dead center TDCe, while the ordinate indicates an amount of displacement in the rotational axis L direction of the top surfaces 51 of the pistons 50 when referenced to the symmetry plane P. As explained above, the pistons 50 move together with the followers 80 along the profiles of the cams 70. Therefore, the behavior of the pistons 50 shown in FIG. 8 shows the profiles of the cams 70. As will be understood from FIG. 8, the pistons 50 reciprocate in the rotational axis L direction as the cylinder 10 rotates about the rotational axis L.

[0031] As explained above, the internal combustion engine 1 of the embodiment according to the present disclosure is a four-stroke engine. In a four-stroke engine, an intake stroke, compression stroke, expansion stroke, and exhaust stroke, which form one combustion cycle, are successively and repeatedly performed. In the embodiment according to the present disclosure, the intake stroke corresponds to a rotational angle range from a top dead center TDCe to a bottom dead center BDCc. The compression stroke corresponds to a rotational angle range from the bottom dead center BDCc to a top dead center TDCc. The expansion stroke corresponds to a rotational angle range from the top dead center TDCc to a bottom dead center BDCe. The exhaust stroke corresponds to a rotational angle range from the bottom dead center BDCe to the top dead center TDCe. Therefore, in the embodiment according to the present disclosure, the top dead center TDCe is an exhaust top dead center, the bottom dead center BDCc is a compression bottom dead center, the top dead center TDCc is a compression top dead center, and the bottom dead center BDCe is an exhaust bottom dead center.

[0032] Further, in the embodiment according to the present disclosure, if the cylinder 10 rotates 180 degrees about the rotational axis L, one combustion cycle is performed. In other words, the profiles of the cams 70 are formed so that every time the cylinder 10 rotates once about the rotational axis L, two combustion cycles are performed. Therefore, the profiles of the cams 70 corresponding to the rotational angle θ of the cylinder 10 of 0 to 180 degrees and the profile of the cam 70 corresponding to the rotational angle θ of the cylinder 10 of 180 to 360 degrees are identical to each other. In other words, positions of the pistons 50 or followers 80a, 80b in the rotational axis L direction at a certain rotational angle θ ($0 \leq \theta \leq 180$ degrees) and positions of the pistons 50 or followers 80a, 80b in the rotational axis L direction at a rotational angle $\theta + 180$ degrees are identical to each other. Furthermore, in other words, in the embodiment ac-

cording to the present disclosure, the profiles of the cams 70 are formed to have 180 degree symmetry about the rotational axis L. However, the profiles of the cams 70 of the embodiment according to the present disclosure does not have 90 degree symmetry about the rotational axis L.

[0033] Furthermore, in the embodiment according to the present disclosure, the above-mentioned intake angle range IN is set to a range from the exhaust top dead center TDCe to the compression bottom dead center BDCc, that is, the intake stroke (for example, see FIG. 8). In another embodiment (not shown), the intake angle range IN starts from a rotational angle θ of the cylinder 10 different from the exhaust top dead center TDCe. Further, in another embodiment (not shown), the intake angle range IN ends at a rotational angle θ of the cylinder 10 different from the compression bottom dead center BDCc. Further, in the embodiment according to the present disclosure, the exhaust angle range EX is set to a range from the exhaust bottom dead center BDCe to the exhaust top dead center TDCe, that is, the exhaust stroke (for example, see FIG. 8). In another embodiment (not shown), the exhaust angle range EX starts from a rotational angle θ of the cylinder 10 different from the exhaust bottom dead center BDCe. Further, in another embodiment (not shown), the exhaust angle range EX ends at a rotational angle θ of the cylinder 10 different from the exhaust top dead center TDCe.

[0034] In the embodiment according to the present disclosure, furthermore, the ignition angle range SP is set to a range around the compression top dead center TDCc (for example, see FIG. 8). In another embodiment (not shown), the ignition angle range SP is set to a rotational angle θ of the cylinder 10 different from one around the compression top dead center TDCc.

[0035] FIGS. 9(A), 9(B), and 9(C) schematically show the internal combustion engine 1 of the embodiment according to the present disclosure in the intake stroke. In the intake stroke, the pistons 50, 50 move so as to separate from each other. As a result, the volume of the combustion chamber 30 increases. At this time, the communication holes 90a communicate with the intake hole 90i. As a result, intake gas (for example, an air-fuel mixture) flows from the intake pipe 91i to the combustion chamber 30.

[0036] FIGS. 10(A), 10(B), and 10(C) schematically show the internal combustion engine 1 of the embodiment according to the present disclosure in the compression stroke. In the compression stroke, the pistons 50, 50 move so as to approach each other. At this time, the communication holes 90a, 90b are closed and, therefore intake gas in the combustion chamber 30 is compressed.

[0037] FIGS. 11(A), 11(B), and 11(C) schematically show the internal combustion engine 1 of the embodiment according to the present disclosure when the rotational angle θ of the cylinder 10 is within the ignition angle range SP or around the compression top dead center TDCc. Around the compression top dead center TDCc where the ignition angle range SP is set, the combustion

chamber 30 is mainly defined in the recessed parts 52, 52 of the facing pistons 50, 50. On the other hand, in the embodiment according to the present disclosure, the pistons 50, 50 are respectively formed so that when the rotational angle θ of the cylinder 10 is within the ignition angle range SP, the notches 52a, 52b of the pistons 50 face the communication holes 90a, 90b. As a result, when the rotational angle θ of the cylinder 10 reaches the ignition angle range SP, the spark plug 91s faces the combustion chamber 30 through the communication holes 90a and notches 52a or communication holes 90b and notches 52b (see FIGS. 11 and 12). At this time, an ignition action by the spark plug 91s is performed. As a result, the air-fuel mixture inside the combustion chamber 30 is ignited and burned.

[0038] FIGS. 13(A), 13(B), and 13(C) schematically show the internal combustion engine 1 of the embodiment according to the present disclosure in the expansion stroke. In the expansion stroke, the communication holes 90a, 90b are closed. Therefore, due to combustion, the pistons 50, 50 move to be separated from each other.

[0039] FIGS. 14(A), 14(B), and 14(C) schematically show the internal combustion engine 1 of the embodiment according to the present disclosure in the exhaust stroke. In the exhaust stroke, the pistons 50, 50 move so as to approach each other. At this time, the communication hole 90b communicates with the exhaust hole 90e. As a result, exhaust gas flows from the combustion chamber 30 into the exhaust pipe 91e.

[0040] In the next combustion cycle, in the intake stroke, the intake hole 90i communicates with the communication hole 90b. Around the compression top dead center TDCc, the spark plug 91s faces the combustion chamber 30 through the communication hole 90b. In the exhaust stroke, the exhaust hole 90e communicates with the communication hole 90a.

[0041] Here, if referring to the number of combustion cycles performed each time the cylinder 10 rotates once about the rotational axis L as a "combustion cycle number", the combustion cycle number of the embodiment according to the present disclosure is set to 2 (for example, see FIG. 8). In another embodiment (not shown), the combustion cycle number is set to one or three or more. Further, in the embodiment according to the present disclosure, a single intake hole 90i, a single exhaust hole 90e, and a single spark plug housing hole 90s are provided and the communication holes of the same number as the combustion cycle number are provided separated at equal intervals in the circumferential direction about the rotational axis L. In another embodiment (not shown), the number of the intake holes is the same as the number of combustion cycles, the number of exhaust holes is the same as the number of combustion cycles, and number of the spark plug housing holes is the same as the number of combustion cycles and are provided separated at equal intervals in the circumferential direction about the rotational axis L and a single communication hole is provided.

[0042] Next, while referring to FIG. 15 to FIG. 17, the internal combustion engine 1 of the embodiment according to the present disclosure will be further explained. Note that FIG. 15 to FIG. 17 show the drive part 40 at the right side in FIG. 3 and FIG. 4, for example. Further, *outward in the rotational axis L direction* means a direction from a top dead center toward a bottom dead center, while *inward in the rotational axis L direction* means a direction from a bottom dead center toward a top dead center.

[0043] In the expansion stroke, as shown in FIG. 15, combustion performed in the combustion chamber 30 causes a force F11 outward in the rotational axis L direction to act on the piston 50 and the followers 80a, 80b integral with the same. As a result, a reaction force F12 in a direction vertical to the cam face 23i acts on the followers 80a, 80b through engagement between the rollers 83, 83 of the followers 80a, 80b and the cam face 23i of the cam 70. As a result, a force F13 in the circumferential direction about the rotational axis L acts on the cylinder 10 through engagement between the engaging surfaces 81d, 81d of the sliders 81, 81 of the followers 80a, 80b and the engaging surfaces 61d, 61d of the slots 60a, 60b of the cylinder 10. Therefore, the cylinder 10 is rotated in the circumferential direction R about the rotational axis L. That is, when combustion is performed in the combustion chamber 30, the piston 50 moves together with the followers 80a, 80b along the profile of the cam 70, to thereby rotate the cylinder 10 about the rotational axis L. In this way, movement of the piston 50 in the rotational axis L direction is converted to rotary motion about the rotational axis L. This rotary motion is taken out as engine output from the output shaft (not shown) coupled with the projecting part 13 of the cylinder 10 (for example, see FIGS. 2 to 4).

[0044] On the other hand, in the compression stroke and the exhaust stroke, as shown in FIG. 16, rotation of the cylinder 10 in the circumferential direction R about the rotational axis L causes a force F21 in the circumferential direction about the rotational axis L to act on the followers 80a, 80b through engagement between the engaging surfaces 61u, 61u of the slots 60a, 60b of the cylinder 10 and the engaging surfaces 81u of the sliders 81, 81 of the followers 80a, 80b. As a result, a reaction force F22 in a direction vertical to the cam face 23i acts on the followers 80a, 80b through engagement between the rollers 83, 83 of the followers 80a, 80b and the cam face 23i of the cam 70. As a result, a force F23 inward in the rotational axis L direction acts on the followers 80a, 80b and piston 50. Therefore, the piston 50 moves inward in the rotational axis L direction.

[0045] In the intake stroke, as shown in FIG. 17, rotation of the cylinder 10 in the circumferential direction R about the rotational axis L causes a force F31 in the circumferential direction about the rotational axis L to act on the followers 80a, 80b through engagement of the engaging surfaces 61u, 61u of the slots 60a, 60b of the cylinder 10 and the engaging surfaces 81u of the sliders

81, 81 of the followers 80a, 80b. As a result, a reaction force F32 in a direction vertical to the cam face 22o acts on the followers 80a, 80b through engagement between the rollers 83, 83 of the followers 80a, 80b and the cam face 22o of the cam 70. As a result, a force F33 outward in the rotational axis L direction acts on the followers 80a, 80b and piston 50. Therefore, the piston 50 moves outward in the rotational axis L direction.

[0046] In this way, in the embodiment according to the present disclosure, reciprocating motion of the piston 50 is converted to rotary motion without using a link mechanism. Therefore, the internal combustion engine 1 can be made more compact. Further, unlike a conventional internal combustion engine using a link mechanism, no thrust force is generated at the piston. Furthermore, the cylinder 10 itself is rotated, so the number of parts is reduced.

[0047] Further, in the embodiment according to the present disclosure, as explained above, two drive parts 40, 40 and, therefore two pistons 50, 50, are provided. In addition, the profiles of the cams 70, 70 are formed so that phases of these pistons 50, 50 are synchronized to each other. As a result, in the intake stroke and expansion stroke, the pistons 50, 50 move to be separated from each other, while in the compression stroke and exhaust stroke, the pistons 50, 50 move so as to approach each other. Therefore, vibration due to the reciprocating motions of the pistons 50, 50 is cancelled out.

[0048] Referring again to FIG. 8, in the embodiment according to the present disclosure, the profiles of the cams 70, 70 are formed so that a stroke length STc from the compression bottom dead center BDCc to the compression top dead center TDCc is shorter than a stroke length STe from the compression top dead center TDCc to the exhaust bottom dead center BDCe. As a result, in the internal combustion engine 1, a mirror cycle which has an expansion ratio larger than a compression ratio is realized. Therefore, the operating efficiency of the internal combustion engine 1 is increased more. In another embodiment (not shown), the profiles of the cams 70, 70 are formed so that the stroke length STc from the compression bottom dead center BDCc to the compression top dead center TDCc and the stroke length STe from the compression top dead center TDCc to the exhaust bottom dead center BDCe are equal to each other. In this case, in the internal combustion engine 1, an Otto cycle which has an expansion ratio and a compression ratio equal to each other is realized.

[0049] The internal combustion engine 1 of the embodiment according to the present disclosure is provided with an electronic control unit (not shown). This electronic control unit is comprised of a digital computer provided with a processor, memory, input port, and output port, which are mutually connected. For example, a rotational angle sensor (not shown) detecting a rotational angle of the cylinder 10 and a load sensor detecting a load of the internal combustion engine 1 are connected to the input port, while, for example, a spark plug 91s, fuel injector,

and throttle valve are connected to the output port. Programs stored in the memory of the electronic control unit are run by the processor of the electronic control unit whereby various controls are performed.

[0050] FIG. 18 shows an internal combustion engine 1 of another embodiment according to the present disclosure. The internal combustion engine 1 of the other embodiment differs in configuration from the internal combustion engine 1 of the above-mentioned embodiment in that it is provided with a single drive part 40. In this case, the combustion chamber 30 is defined between the top surface of the piston 50 and the end face 14 in the rotational axis L direction of the cylinder 10. The rest of the configuration of the internal combustion engine 1 of the other embodiment according to the present disclosure is similar to the configuration of the internal combustion engine 1 of the above-mentioned embodiment according to the present disclosure, and therefore explanations therefor will be omitted.

[0051] FIGS. 19(A) and 19(B) show another embodiment of the follower 80a. In the embodiment shown in FIGS. 19(A) and 19(B), the arm 82 of the follower 80a is provided with two branched parts 82a, 82a. The branched parts 82a, 82a respectively rotatably hold rollers 83a, 83a. One roller 83a engages with one cam face 22o of the cam 70, while the other roller 83a engages with the other cam face 23i.

[0052] FIGS. 20(A) and 20(B) show another embodiment of the cam 70 and follower 80a. In the embodiment shown in FIGS. 20(A) and 20(B) as well, the arm 82 of the follower 80a is provided with two branched parts 82a, 82a. The branched parts 82a, 82a respectively rotatably hold rollers 83a, 83a. On the other hand, the cam 70 has a shape of a projection projecting out from the inner circumferential surface 21 of the outer circumferential member 20. Two side surfaces of this projection form cam faces. One roller 83a engages with one cam face of the cam 70, while the other roller 83a engages with the other cam face.

[0053] In the various embodiments according to the present disclosure explained above, fuel is injected from a fuel injector attached to the intake pipe 91i into the intake pipe 91i. In another embodiment according to the present disclosure (not shown), fuel is directly injected from the fuel injector attached to the outer circumferential member 20 into the combustion chamber 30. In this case, the fuel injector is housed in a fuel injector housing hole formed in the outer circumferential member 20, and is arranged on the inner circumferential surface 21 of the outer circumferential member 20 so as to face the communication holes 90a, 90b when the rotational angle of the cylinder 10 is within a predetermined injection angle range.

[0054] Further, in the various embodiments according to the present disclosure explained above, the profile of the cam 70 is formed to have 180 degree symmetry, without having 90 degree symmetry, in the circumferential direction about the rotational axis L. In another embodi-

ment according to the present disclosure (not shown), the profile of the cam 70 is formed to have a predetermined angle symmetry in the circumferential direction about the rotational axis L. In one example, one example of the predetermined angle is 90 degrees. Furthermore, in another embodiment (not shown), the profile of the cam 70 is formed asymmetric in the circumferential direction about the rotational axis L.

[0055] On the other hand, in the various embodiments according to the present disclosure explained above, the drive part 40 is provided with two slots 60a, 60b. In another embodiment according to the present disclosure (not shown), the drive part 40 is provided with one or three or more slots 60.

[0056] Further, in the various embodiments according to the present disclosure explained above, the drive part 40 is provided with two followers 80a, 80b. In another embodiment according to the present disclosure (not shown), the drive part 40 is provided with one or three or more followers 80. Here, the number of followers 80 is the same as or smaller than the number of slots 60.

[0057] However, if the profile of the cam 70 has 180 degree symmetry about the rotational axis L, rather than 90 degree symmetry, one or two followers 80 are provided. If the profile of the cam 70 has 90 degree symmetry about the rotational axis L, one, two, or four followers 80 are provided. Therefore, expressed comprehensively, the profile of the cam 70 is formed to have a predetermined angle symmetry in the circumferential direction about the rotational axis L, and the follower 80 is comprised of a plurality of followers separated from each other at equal intervals in the circumferential direction about the rotational axis L, and the number of followers is determined according to the predetermined angle. Increasing of the number of followers 80 reduces or limits loads acting on the followers 80.

[0058] In another embodiment according to the present disclosure (not shown), the slider 81 of the follower 80 is omitted. In this case, for example, the arm 82 engages with the engaging surfaces 61u, 61d of the slot 60a. In still another embodiment according to the present disclosure (not shown), the roller 83 of the follower 80 is omitted. In this case, for example, the arm 82 engages with the cam surface of the cam 70.

REFERENCE SIGNS LIST

[0059]

- 1 internal combustion engine
- 10 cylinder
- 20 outer circumferential member
- 30 combustion chamber
- 40 drive part
- 50 piston
- 60 slot
- 70 cam
- 80 follower

L rotational axis

Claims

1. An internal combustion engine, comprising:

a cylinder able to rotate about a rotational axis;
a combustion chamber defined in the cylinder;
and
a drive part, the drive part comprising:

the drive parts comprised of

a piston housed in the cylinder to be able to slide in a direction of the rotational axis and defining the combustion chamber;
a slot formed in a circumferential surface of the cylinder at an opposite side to the combustion chamber relative to the piston;
a cam stationarily set around the slot, which cam has a profile oscillating in a direction of the rotational axis while being annular in a circumferential direction of the rotational axis; and
a follower extending from the piston through the slot to the cam, and configured to move together with the piston along profile of the cam,

wherein the slot is configured to limit relative movement of the follower together with the piston with respect to the cylinder in a circumferential direction of the rotational axis, while allowing relative movement of the follower together with the piston with respect to the cylinder in a direction of the rotational axis,
wherein combustion performed in the combustion chamber moves the piston together with the follower along profile of the cam to thereby rotate the cylinder about the rotational axis, and
wherein the rotation of the cylinder is taken out as engine output.

2. The internal combustion engine according to claim 1,

wherein the drive part comprises two drive parts arranged along the rotational axis,
wherein the combustion chamber is defined in the cylinder between the pistons of the two drive parts, and
wherein the profiles of the cams are formed so that the pistons of the two drive parts are synchronized to each other.

3. The internal combustion engine according to claim 1 or 2, wherein the internal combustion engine is a four-stroke internal combustion engine.

4. The internal combustion engine according to claim 3, wherein the profile of the cam is formed so that a stroke length from compression bottom dead center to compression top dead center is shorter than a stroke length from compression top dead center to exhaust bottom dead center.

5. The internal combustion engine according to any one of claims 1 to 4,

wherein the profile of the cam is formed to have a predetermined angle symmetry in the circumferential direction about the rotational axis, and wherein the follower is comprised of a plurality of followers separated from each other at equal intervals in the circumferential direction about the rotational axis, the number of the followers being determined according to the predetermined angle.

6. The internal combustion engine according to claim 5,

wherein the profile of the cam is formed to have 180 degree symmetry about the rotational axis, rather than 90 degree symmetry, and wherein the follower is comprised of two followers separated from each other at equal intervals in the circumferential direction about the rotational axis.

7. The internal combustion engine according to any one of claims 1 to 6, further comprising an outer circumferential member stationarily set around the cylinder.

8. The internal combustion engine according to claim 7, further comprising:

a communication hole formed at the circumferential surface of the cylinder so as to communicate with the combustion chamber;
an intake hole formed at the outer circumferential member so as to communicate with the communication hole when a rotational angle of the cylinder is in a predetermined intake angle range; and
an exhaust hole formed at the outer circumferential member so as to communicate with the communication hole when the rotational angle of the cylinder is in a predetermined exhaust angle range.

9. The internal combustion engine according to claim 8,

wherein the communication hole is comprised

of a plurality of communication holes separated from each other at equal intervals in a circumferential direction about the rotational axis, wherein the intake hole is comprised of a single intake hole, and
wherein the exhaust hole is comprised of a single exhaust hole.

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10. The internal combustion engine according to claim 8 or 9, further comprising a spark plug arranged at an inner circumferential surface of the outer circumferential member so as to face the communication hole when the rotational angle of the cylinder is in a predetermined ignition angle range.

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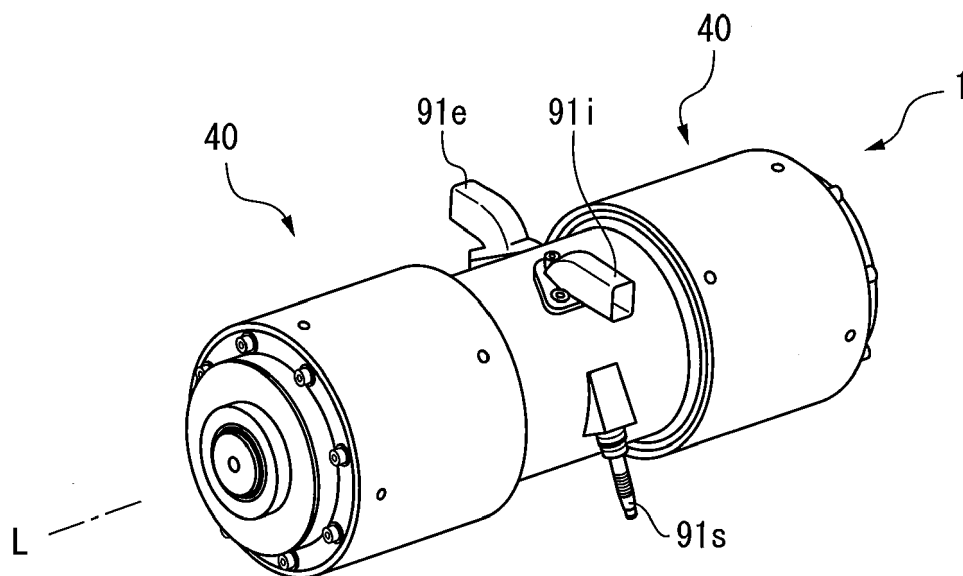
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FIG. 1



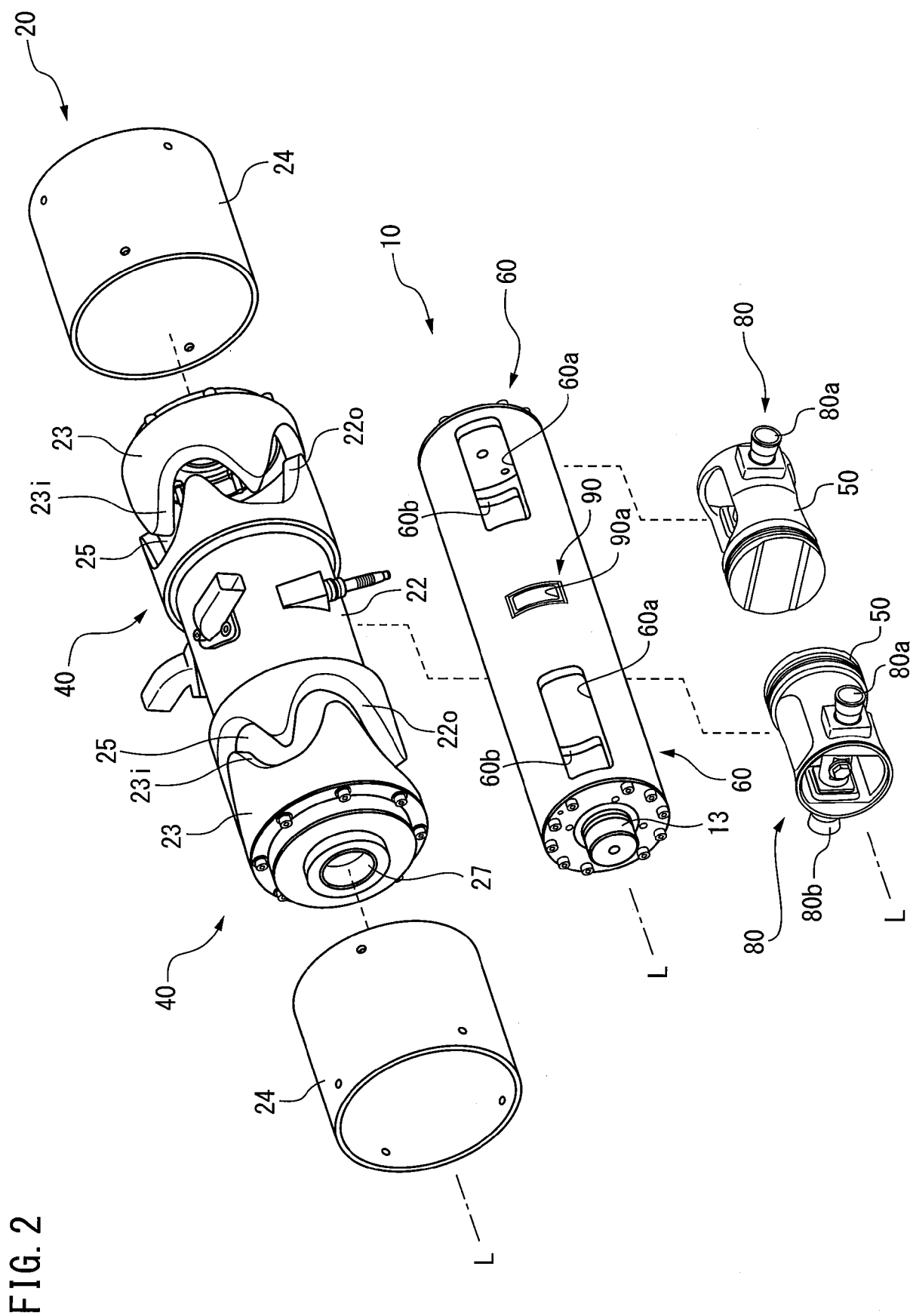


FIG. 3

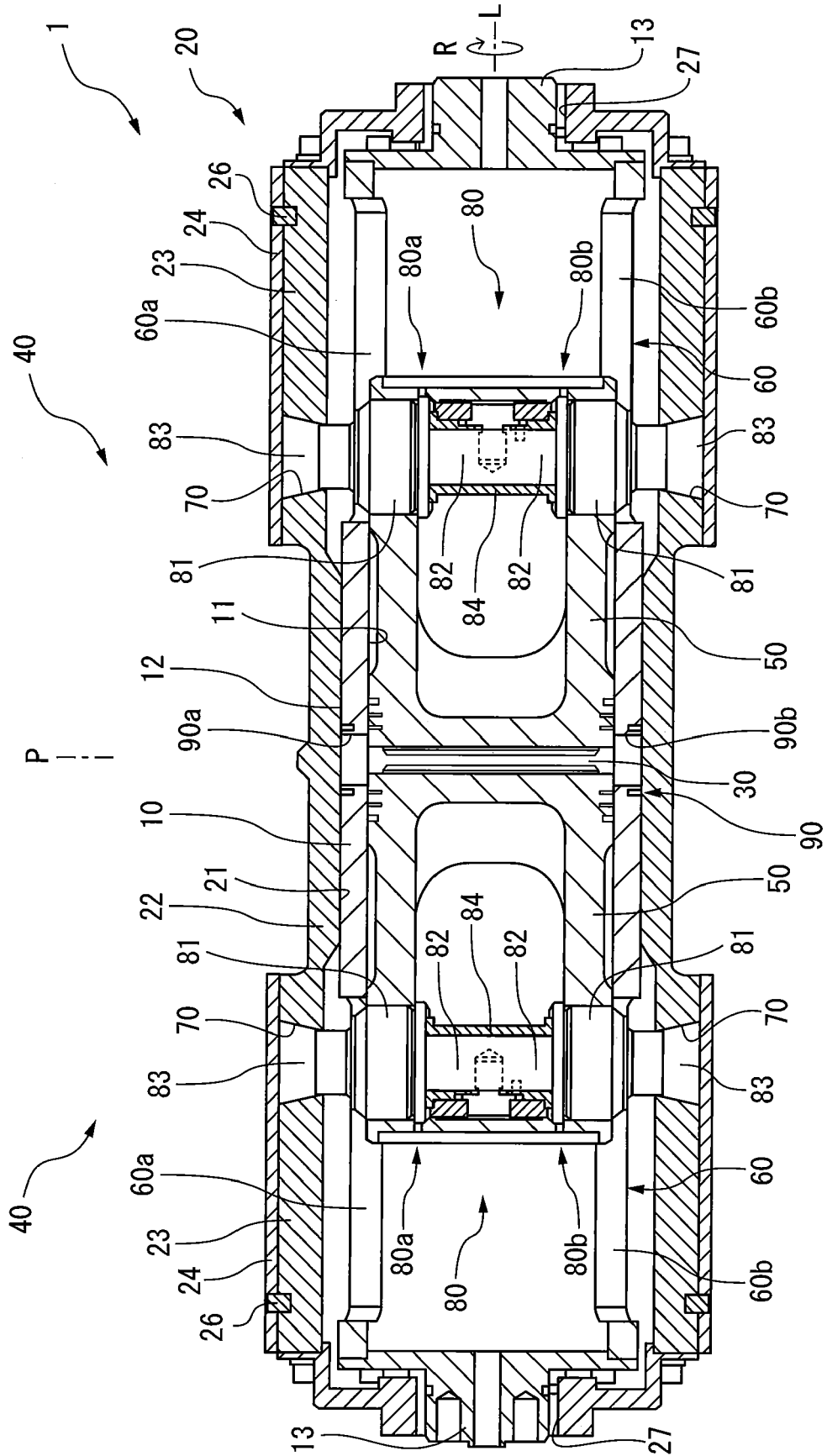


FIG. 4

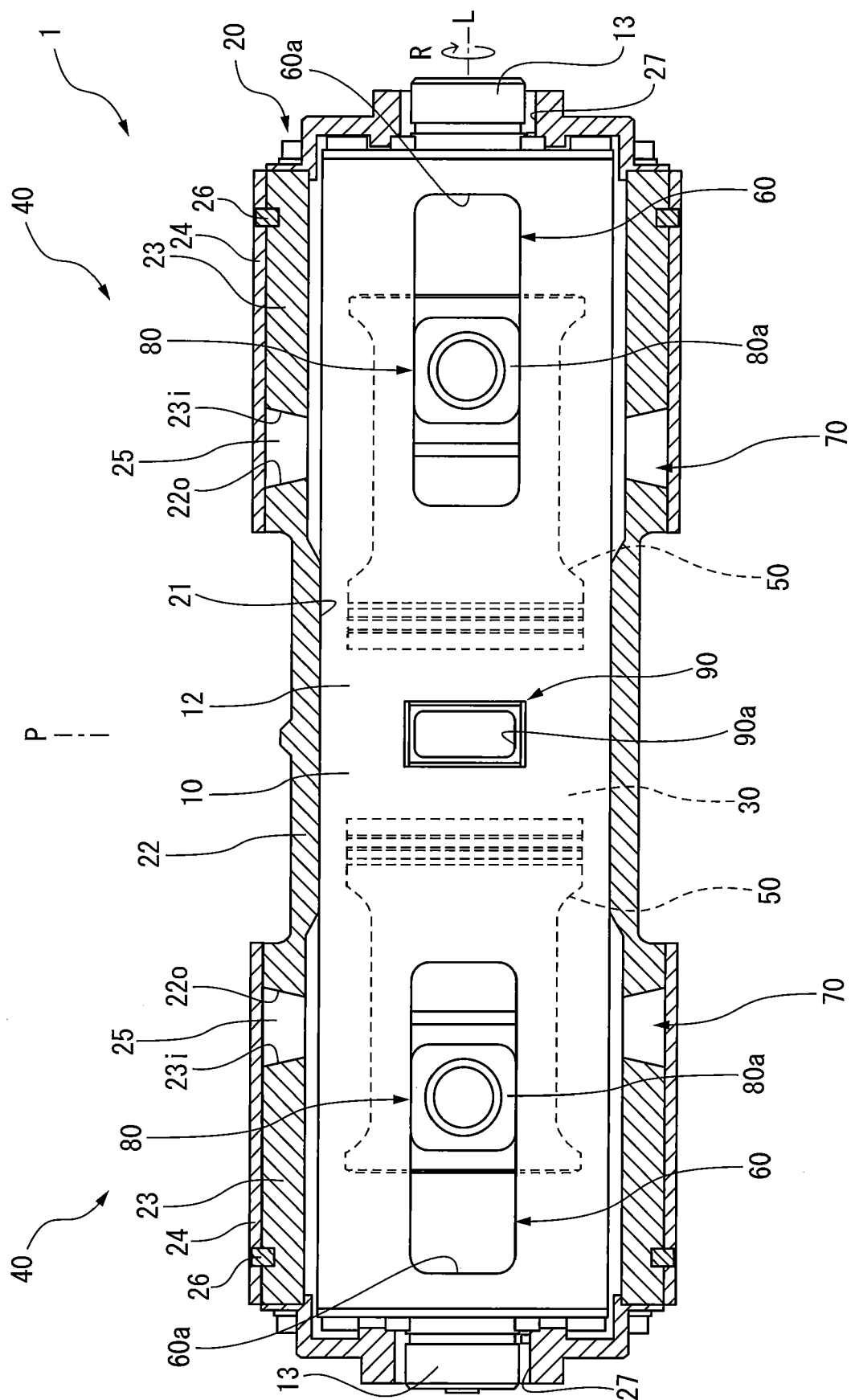


FIG. 5

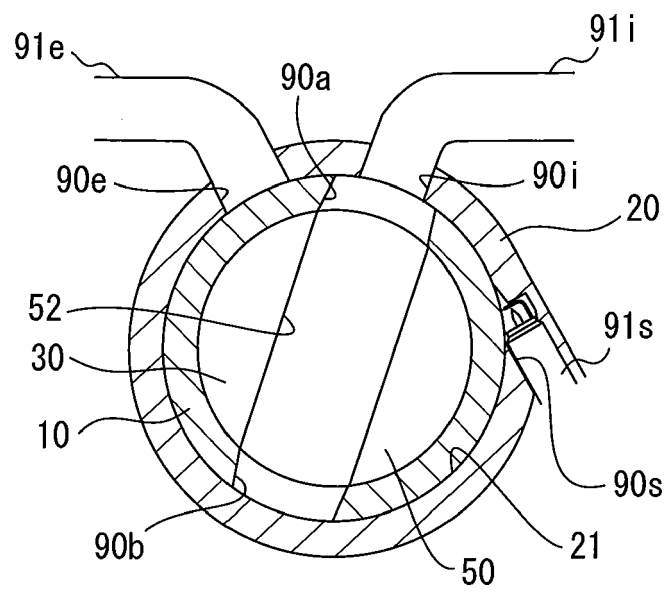


FIG. 6

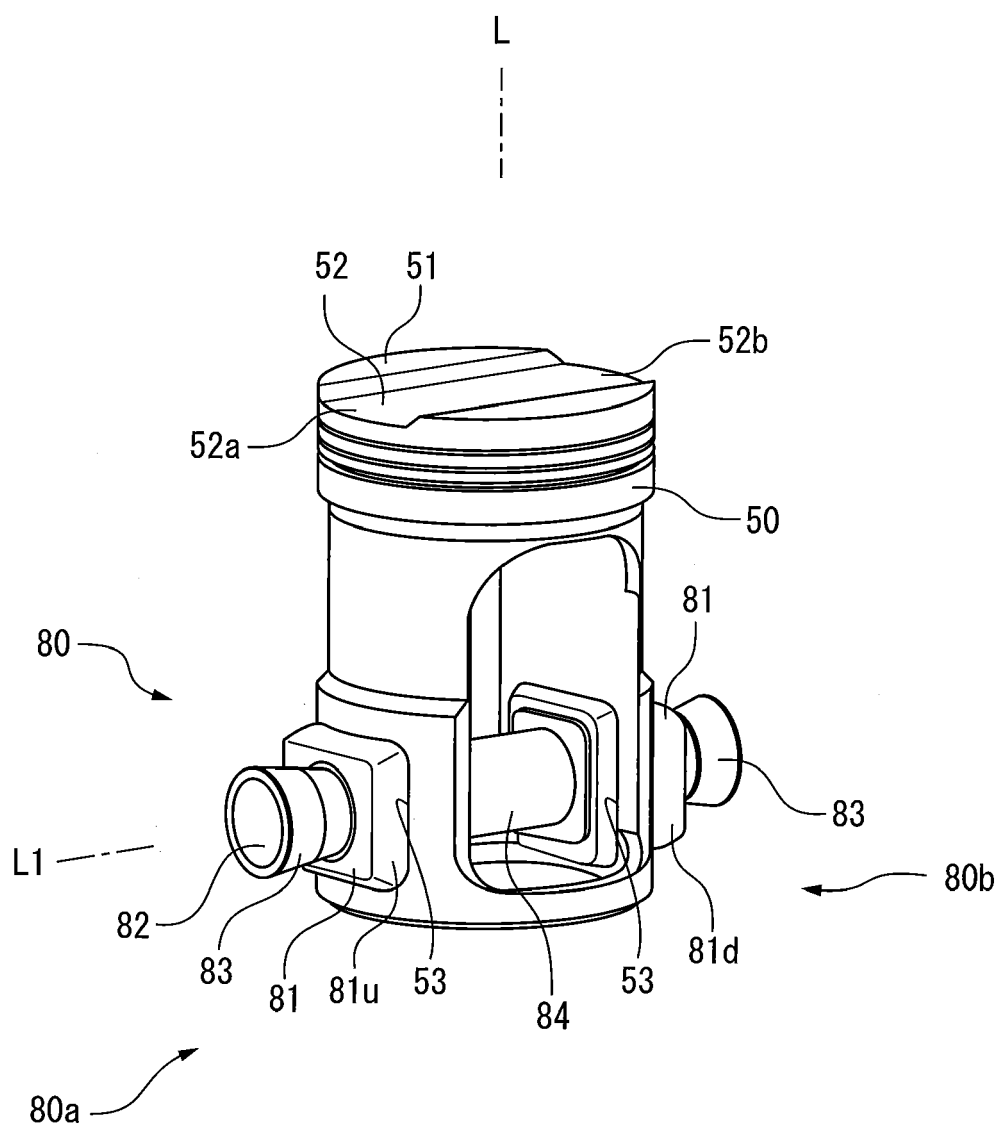


FIG. 7

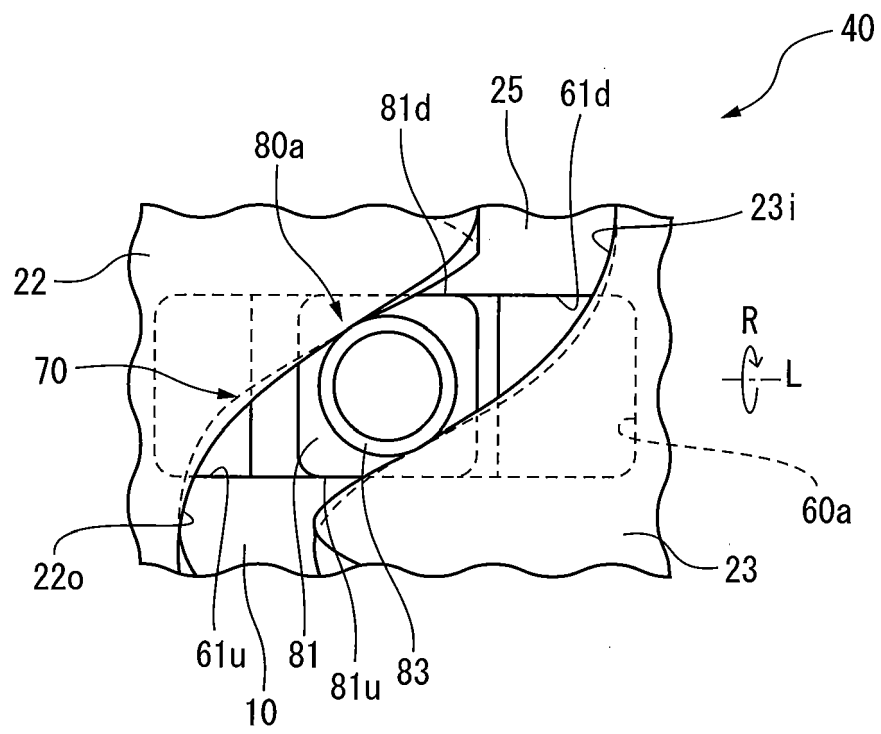


FIG. 8

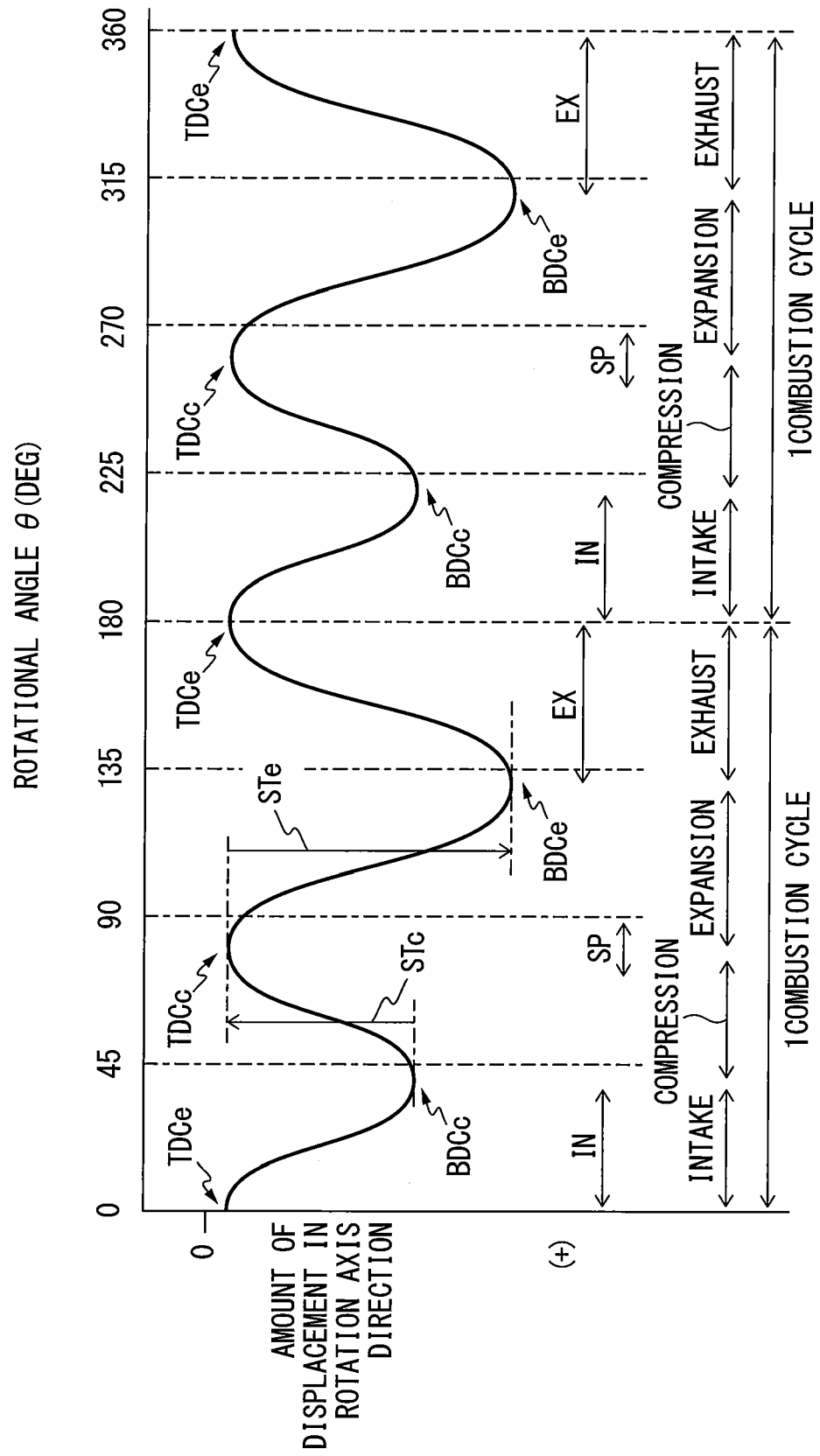


FIG. 9

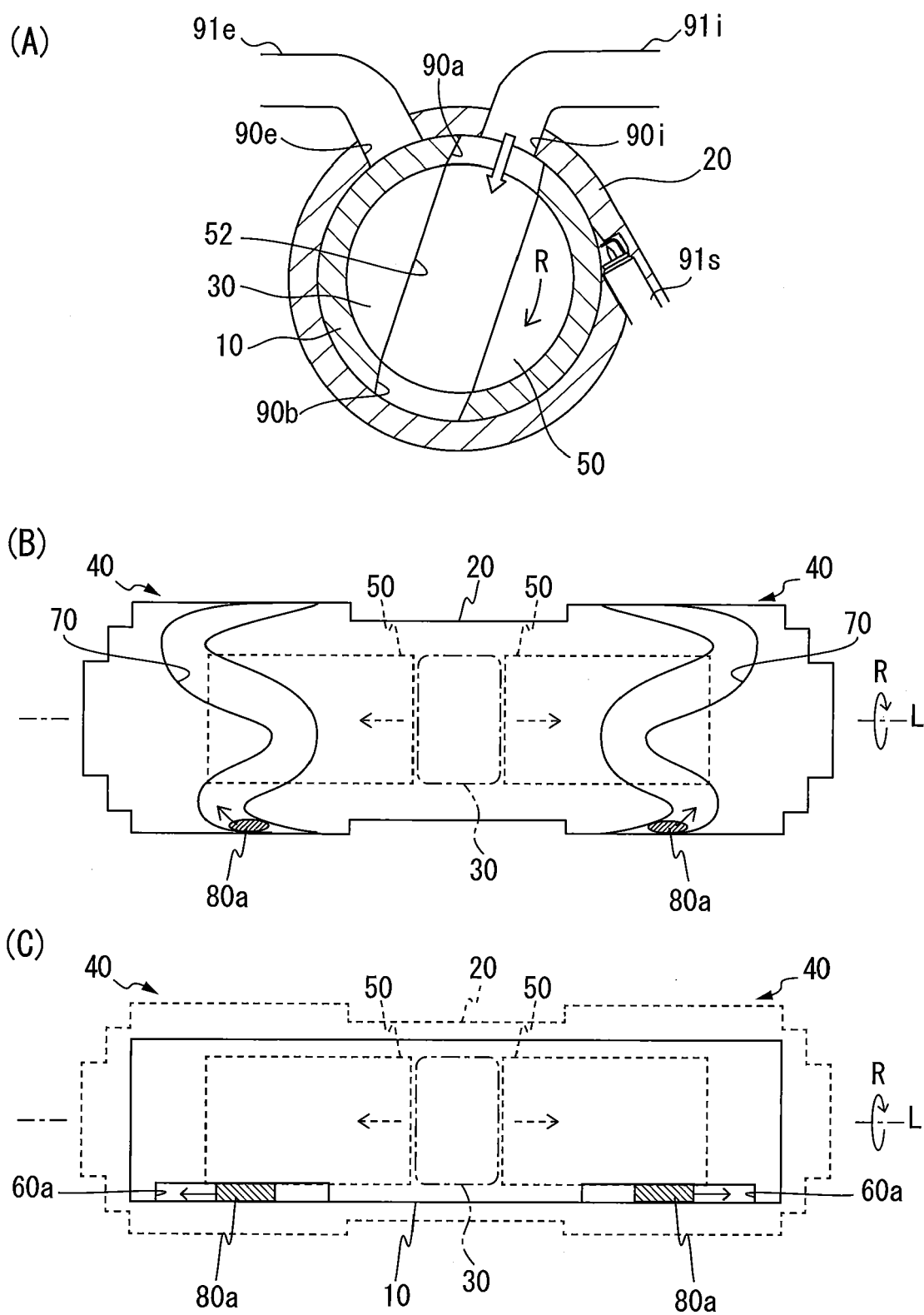


FIG. 10

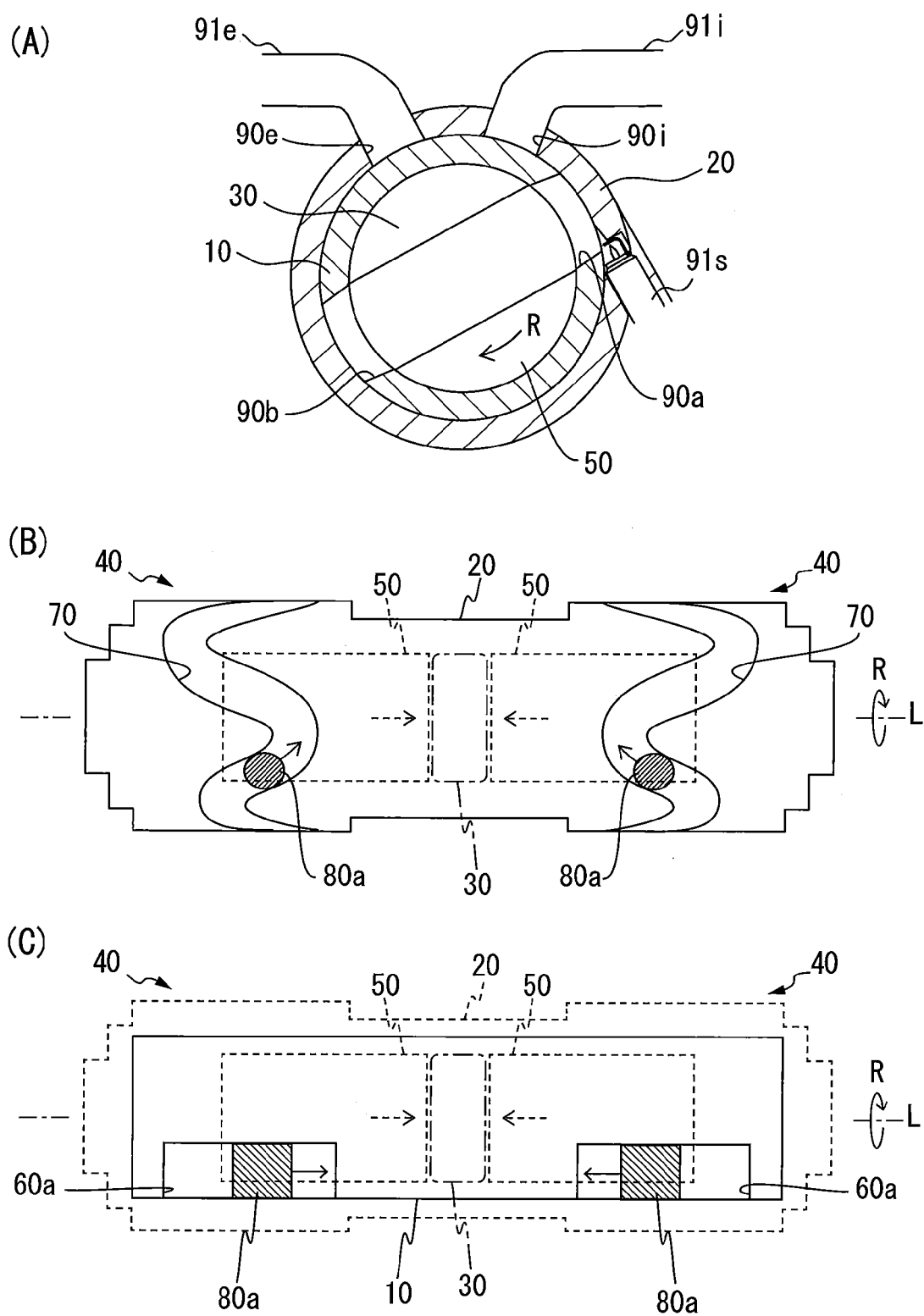


FIG. 11

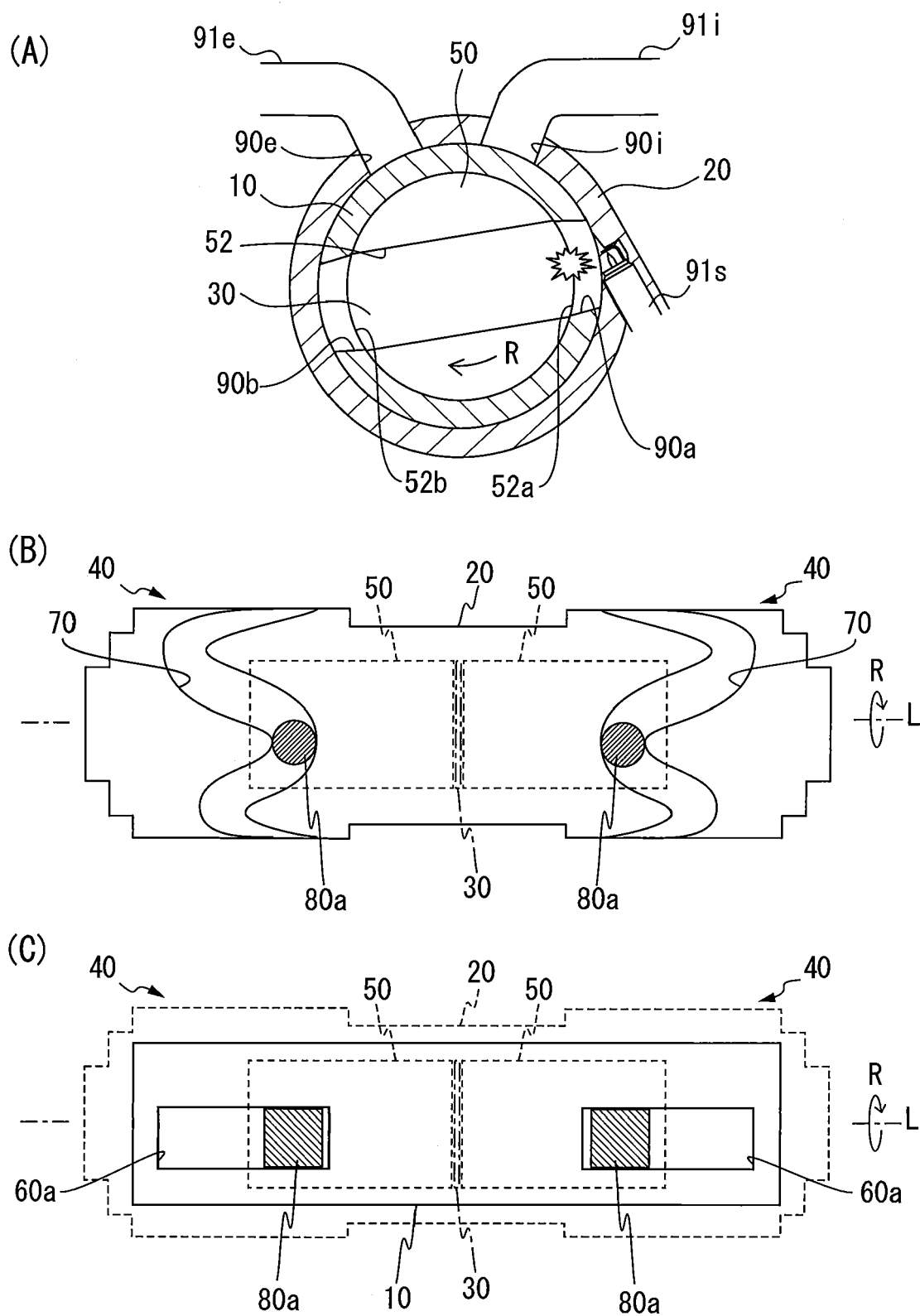


FIG. 12

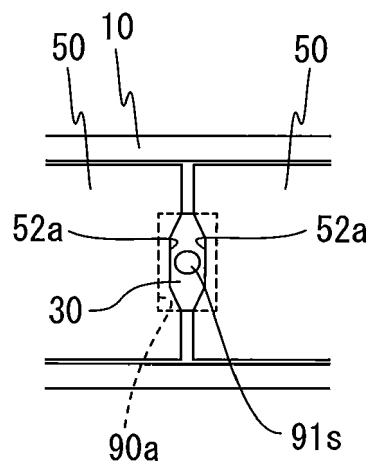


FIG. 13

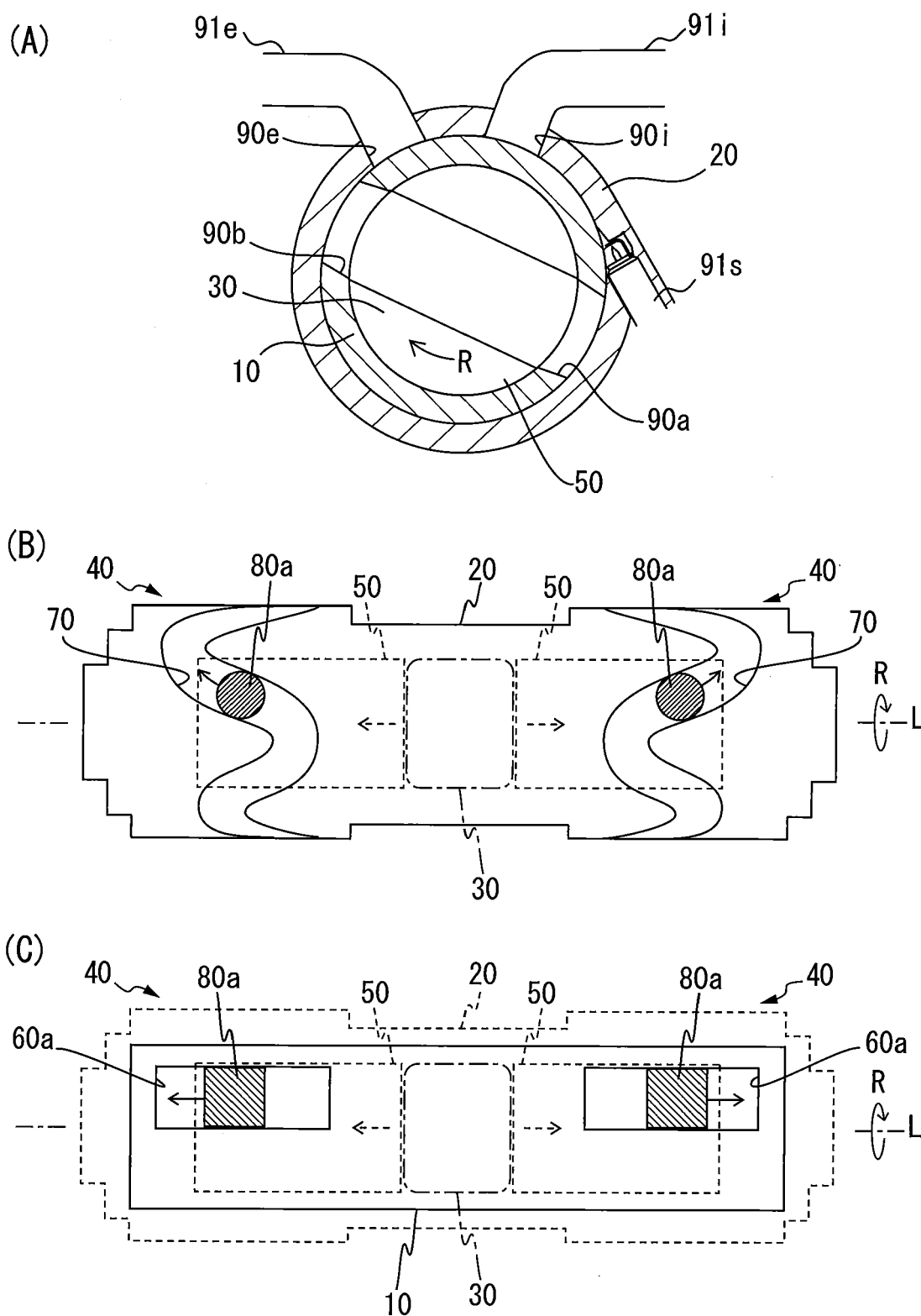


FIG. 14

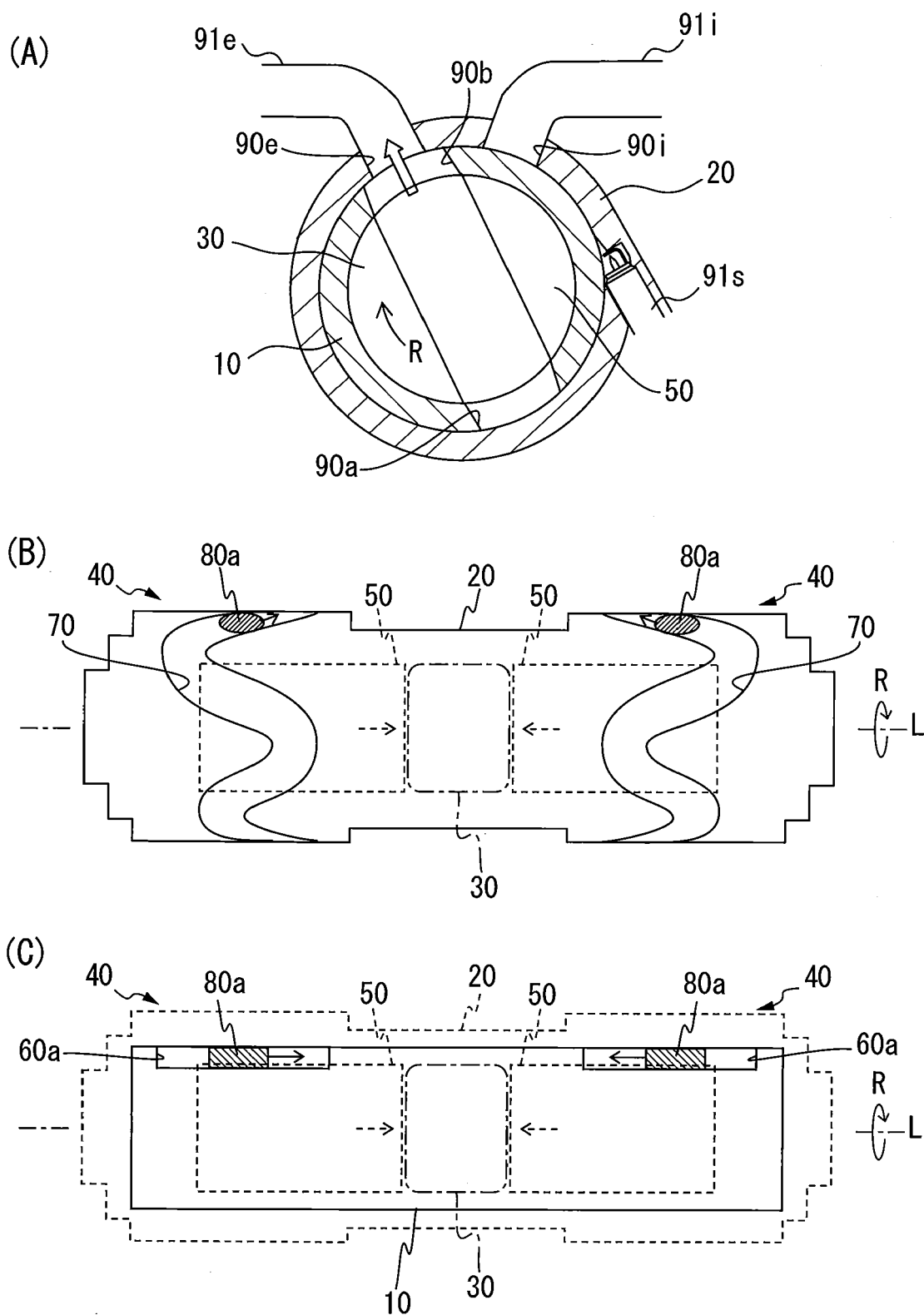


FIG. 15

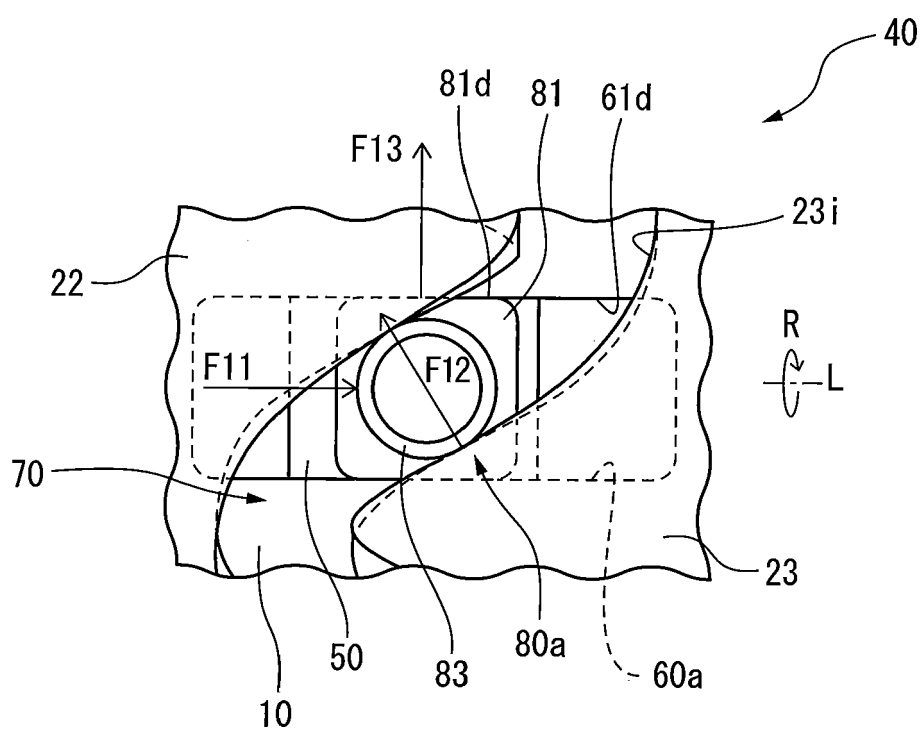


FIG. 16

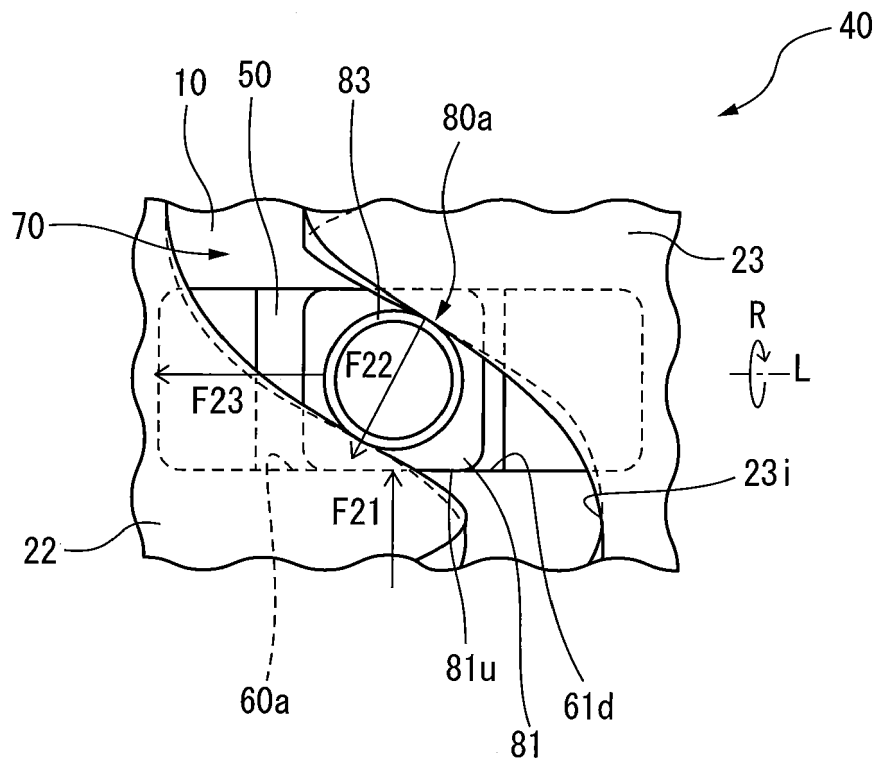


FIG. 17

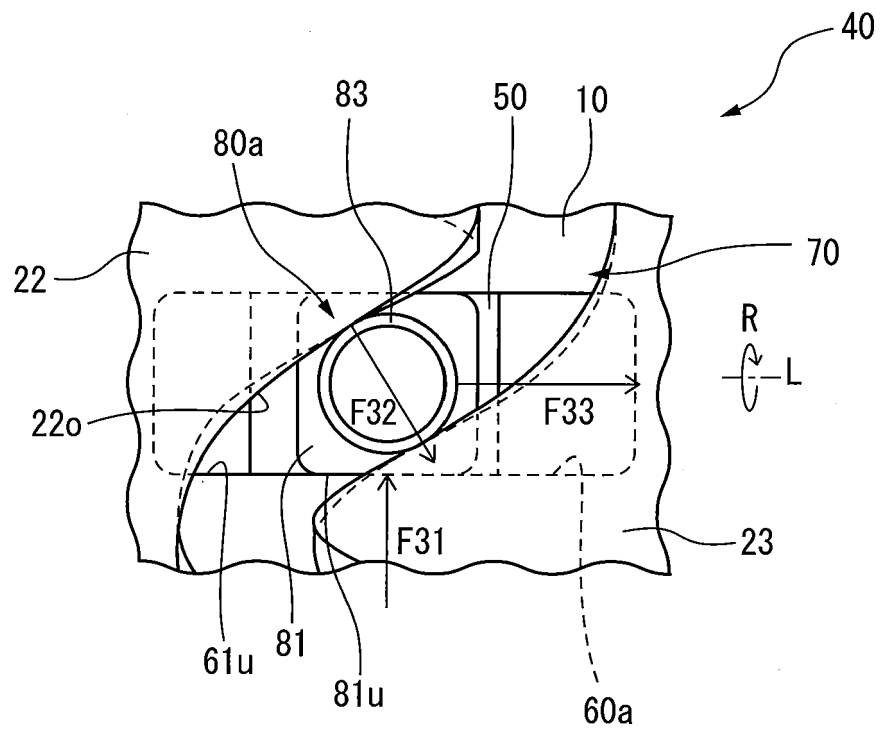


FIG. 18

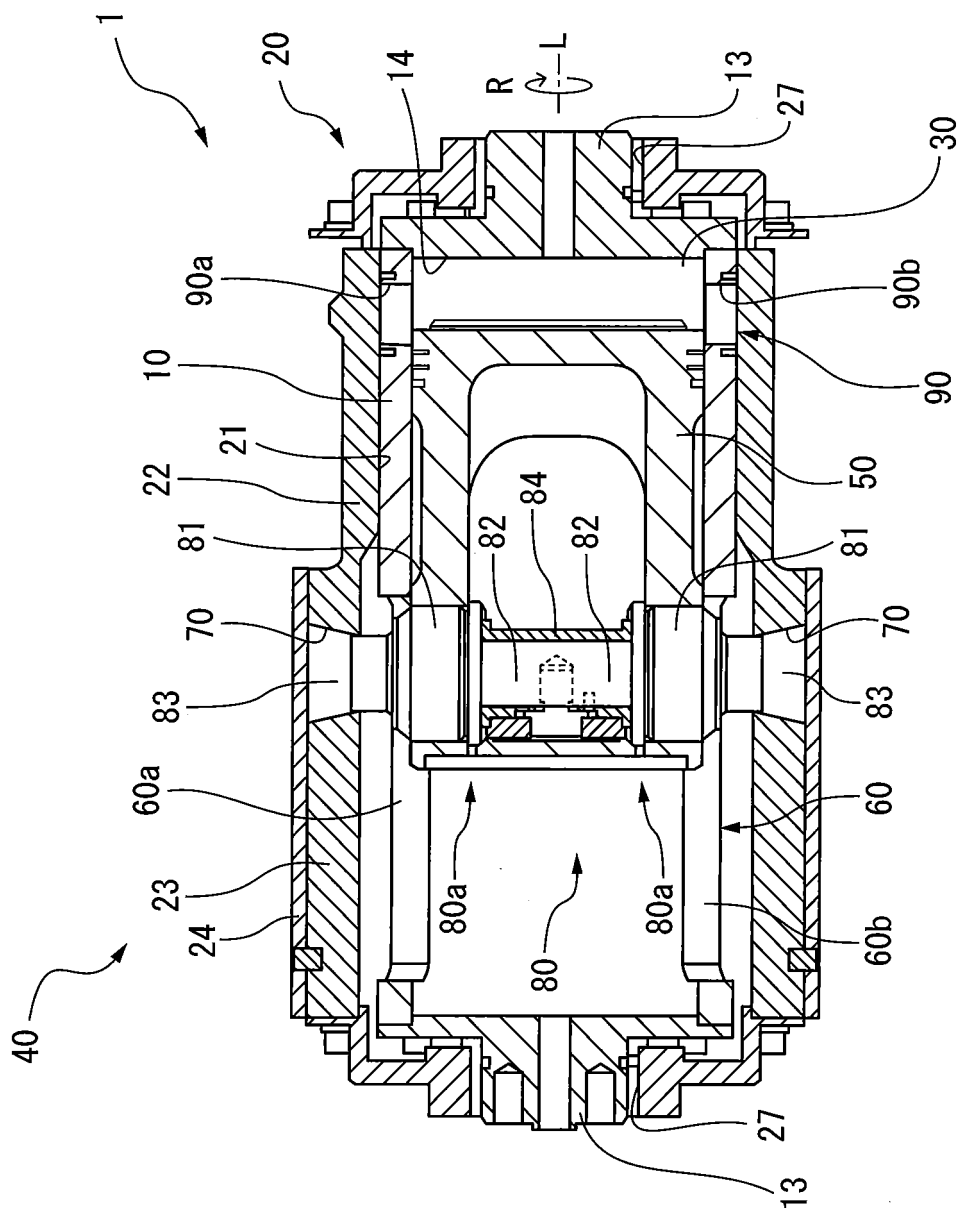
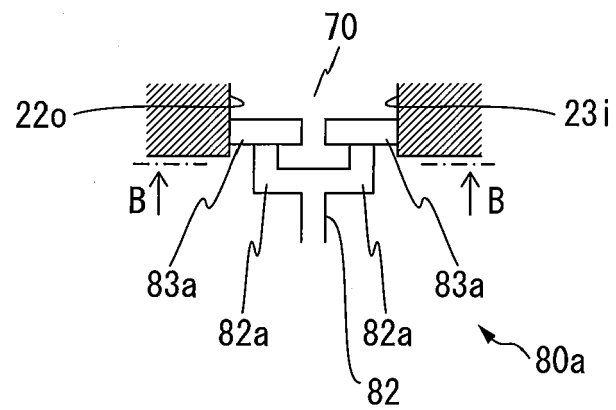


FIG. 19

(A)



(B)

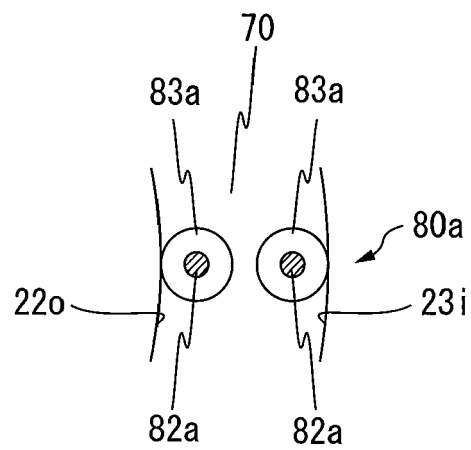
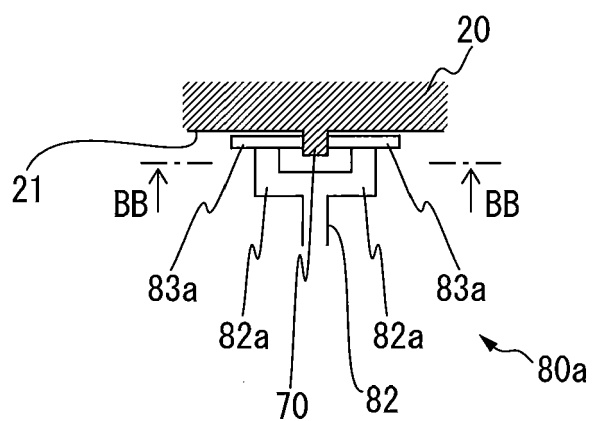
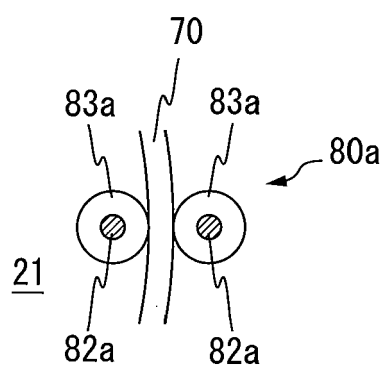


FIG. 20

(A)



(B)





EUROPEAN SEARCH REPORT

Application Number
EP 19 17 1438

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			TECHNICAL FIELDS SEARCHED (IPC)
			F01B F02B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 31 October 2019	Examiner Coniglio, Carlo
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ON EUROPEAN PATENT APPLICATION NO.**

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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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31-10-2019

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